STUDIES IN THE DRIFTLESS REGION OF WISCONSIN.[1]

THE superficial deposits of this region, aside from the interest which would naturally attach to any such deposit, possess a certain special interest due to the relation the region holds to the adjoining glaciated territory, and the presumption that they might furnish a record of certain subsidiary facts which from the nature of the case the glaciated region itself could not furnish.

The field as a whole is a most inviting one for study, presenting as it does considerable variety. But the purpose of this article is more especially to describe a particular deposit as seen in the vicinity of Trempealeau on the Mississippi River. As some knowledge of associated beds is necessary to a full understanding, I will briefly describe them in order beginning with:

The loess.—From the upper limits reached by the Champlain floods, all the smaller valleys, the lower hills, and, in a less degree, the higher hills are covered by a bed of clay, the average thickness of which may be between twenty and thirty feet, but it

[1] Early in 1894 Mr. G. H. Squier brought to the attention of the senior editor of this JOURNAL some observations which he had made on ridges of coarse gravel and bowlders in the vicinity of Tomah, Wis., which lies in the heart of the driftless area. It was his opinion that the formations constituted evidence of local glaciation. The débris was described as made up of chert and sandstone too coarse to be easily accounted for, in his opinion, by floods. It formed ridges on the slopes or side-plains of the valley and neither had the form of definite terraces nor of axial valley drift. No glacial striation either of the transported rock or of the rock *in situ* were observed, nor were glacial contours recognized in the configuration of the valley, nor distinctively in the ridges of débris. These deficiencies of evidence seemed less important however than the apparent absence of limestone débris. The deposit in question seemed to be made up wholly of sandstone, chert, and other residuary material. As limestone lay on the summit and formed the protecting crown of the highlands in which the valleys head, and as its habit of outcrop is such that it could readily yield massive blocks to glaciers occupying the heads of these valleys, and further, as limestone is habitually present in morainic débris formed in such situations.

varies greatly. Two measurements obtained not over ten rods apart, one on the crest of a hill, the other on its west slope, gave seventeen and thirty-two feet, respectively, with indications that at some intermediate point it may reach fifty feet. It is almost wholly free from stones and very homogeneous in texture, though the deeper parts are somewhat lighter in color and more friable, the result apparently of a large admixture of sand. Save in the valleys, it usually overlies the residual material derived from the disintegration of the underlying rocks, or near the foot of the hills, the talus, which being often nearly pure sand well shows the abruptness of the transition. In rare cases it rests directly on the rock.

while it is habitually absent from accumulations formed by weathering and by processes sequent upon weathering, the balance of evidence seemed to me adverse to the glacial hypothesis. At any rate, it seemed best to urge more prolonged and critical study before publication.

In February 1895 Mr. Squier presented similar data more fully worked out with reference to ridges of bowldery material accumulated about Trempealeau bluff on the Mississippi, in the northern part of the driftless area. The absence of limestone cannot be urged here with the same force as at Tomah, since it occurs in at least one locality. The absence of glacial scratches on the transported rocks as well as the valley sides, and the lack of specific morainic contours leave much to be desired here as at Tomah, but these deficiencies are not necessarily fatal to the glacial hypothesis. The conception of Mr. Squier, that the glaciers were formed by snowdrifts lodged in the valleys, and not by summit accumulations, is doubtless the true one if the glacial interpretation be true at all. Examples of such snowdrift valley glaciers occur in the extra-glacial belt in Greenland, and might reasonably enough be supposed to have occurred in the driftless area. But if these deposits are really due to local wind-drift glaciers decisive evidence of the fact should be forthcoming on a sufficiently prolonged and critical search. A coarse massive mixture of residuary material, however difficult of satisfactory explanation by other agencies, cannot safely be taken as in itself proof of glacial origin. It must be remembered that as a result of the excessive superficial thawing and freezing incident to glacier-border conditions, the facilities for landslides, bodily creeps, and similar modes of movement reached an extraordinary degree of development. I have seen in Montana a modern landslide that imitated a glacier almost perfectly in the deployment of its material. In Yellowstone Park, Mr. Hague showed me several years ago an almost perfect imitation of glacial deployment assumed by a talus mass of angular blocks of igneous rock. When such formations consist of mixtures of earthy and rocky material, their positive differentiation from glacial deposits may not be always successfully attained. So long as the constituent material is essentially residuary in origin, and there is an absence of any notable quantity of unweathered rock

Stratified beds.—In the valleys up to about one hundred feet above the river, the loess usually overlies stratified beds. The upper surface of the main body of the beds is not as high as given, but beds of similar character, of no great thickness, persist for a short but indefinite distance up the hillside. The thickest section I have seen shows about fifteen feet without exposing the base. In composition, sand forms by far the most abundant element, especially in the thickest places. Clay is present however, in some places interstratified with sand, and stones not exceeding a few pounds weight are plentifully included, all of local origin. The transition to the overlying loess is abrupt.

Peculiar stratum.—In one valley there is exposed a bed which, though of small size (four feet thick, and but a few rods in extent), possesses considerable interest from the fact that it contains pebbles of extra-local origin (granite, etc.). It intervenes between the stratified beds and the loess and is sharply distinguished from both. It is entirely unstratified, but presents a somewhat mottled appearance due to the imperfect mingling of the component elements, sand, clay, etc. It also contains stones of local origin not exceeding a few pounds weight. Its position both stratigraphically and topographically is such that it cannot be referred

wrested from its place as glaciers are accustomed to wrest a portion of their burden the suspicion of an origin by creep or slide or wash, or at least of some origin other than glacial, is invited.

But in view of the recent article by Mr. Frederick W. Sardeson in the December number of the *American Geologist*, in which the occurrence of glaciation in the driftless area is confidently announced on the basis of much more limited studies than those of Mr. Squier, and upon formations much more open to doubt than those near Tomah and Trempealeau, since they are described as wholly composed of sandstone, chert and earthy matter all referable to the residuary class, while the crowns of the ridges which closely overlook the valley on both sides are limestone, it is obvious that it might be unjust to Mr. Squier to urge longer search for the desired critical data before publication. It is even possible that this urgency in the past and the delay in the publication of his observations may not be free from the appearance of injustice. But fortunately the good judgment of geologists does not, in the better habit of today, rest much upon technical priority, but almost wholly upon the care and the completeness of the investigation. It has seemed only fair to Mr. Squier, however, to state thus fully the extent of his studies and the occasion of the delay in their published appearance.

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to the time of the river gravels, but must be assigned to some earlier period.

Unstratified beds.—Overlaid by the stratified beds where they occur, otherwise by the loess, are certain deposits, which more especially form the subject of this article. They are confined to the valleys, where they have a much greater range than the stratified beds, reaching from two hundred feet or more above present river level to an unknown depth below. They consist characteristically of an aggregation of stones large and small together with the finer material forming the matrix. Although there is a considerable range of variation in the abundance and average size of the stones, in the relative abundance of the different kinds, and in the composition of the matrix, the general facies remains very constant. All the material so far as discovered is of local origin. Owing to a variety of circumstances it is difficult to give the thickness with anything like accuracy.

Details of structure will be best shown in the course of a description of the various exposures. The beds are for the most part entirely concealed from observation by the overlying deposits. It is only in the vicinity of the river where the latter have been wholly or partly removed, or where a deep ravine has penetrated to them that they can be studied.

Descriptive details.—The most extensive exposures occur about a mile and a half west of Trempealeau village. A sketch map of the locality is given in Fig. 1. At this point two old valleys converge so that they partly unite along the river front. The lower parts of these valleys (shown in outline on the map) have been filled up so that the drainage has been deflected, resulting in the formation of new gorges through the rock. Wherever these fillings are open to observation they are seen to consist of unstratified beds having the general characteristics above described. In the east valley loess occurs down to the bottom of the ravine above the filling, many feet below its crest.

The west valley offers rather the most favorable conditions for observation and section 2, Fig. 2, is taken along its axis. The filling takes the form of a well marked ridge extending across

the old valley. It is considerably broader and higher at the east end. At the west end it has been considerably encroached upon by the torrent course. At this end where it abuts against the

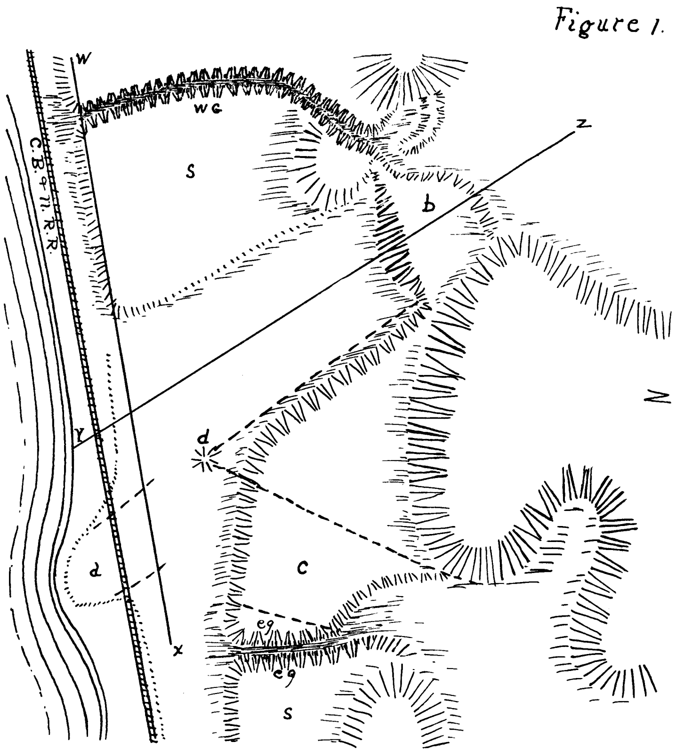

FIG. 1.— Sketch of map of vicinity of Trempealeau, Wis., described in text. Outlines of valleys in broken lines. *wg*, Rock gorge of west valley; *eg*, Rock gorge of east valley; *a*, Point composed of large rock masses; *b*, Transvesre ridge; *c*, Filling of east valley; *d*, Outlying low knob; *ss*, Sandstone plateaus; *wx*, *yz*, Lines of sections.

side of the valley, it meets a projecting spur from the hills, and through this spur the upper end of the rock gorge passes. Surface indications show that material similar to the ridge extends down the east side of the valley as far at least as the low knob *d*, Fig. 1, but its center along the line of section is occupied by nearly pure sand. On the west side gullies show that a bowlder bed

probably exists a few feet below the surface. Above the ridge loess begins and covers all the upper part of the valley. It is seen in the bottom of the ravine as it skirts the ridge, some twenty feet below its crest.

From the knob *d* a concealed ridge extends toward the river terminating in the prominent point *a*. The front of the point is lined with very large masses of rock reaching up to six or seven tons in weight. Excavations show that the entire ridge is composed of like material. The largest masses are usually sandstone. Chert is abundant and all the local rocks are represented. Sand covers the ridge to a depth of two to three feet and fills the valleys on either side to an unknown depth. The general direction of the ridge is shown by occasional protruding bowlders. As shown on the map, this ridge extends almost entirely across the course of the east valley. Yet its direction and other circumstances seem to indicate that it belongs structurally to both valleys.

About half a mile east of the two valleys just described occurs another, the largest in the Trempealeau bluffs. (It is the one in which the bed containing pebbles of extra local origin occurs.) At its mouth, on the east side, a bowlder bed is superimposed on the edge of a sandstone plateau (sec. 3, Fig. 2). In the size and character of the material, in structure, etc., it is a fairly representative example, although not as thick as most. No similar deposit is to be seen on the other side, although I should expect to find one under the sand. In the upper parts of this valley some interesting sections are furnished by washouts; owing, however, to their incompleteness they, for the most part, leave one in doubt as to the true nature of the structure displayed.

In one place the point of a hill has been washed away, showing that at that point the hill consists of a bowlder bed of characteristic type, the material being piled nearly as steeply as it will lie. The top and sides are covered with loess. The entire junction is visible, showing that the transition is as abrupt as possible (sec. 4). It cannot be seen whether it is part of a

ridge stretching across the valley or not. Less than a quarter of a mile east of this valley is another small one descending from the west side of the principal bluff. It first leaves the

Figure 2.

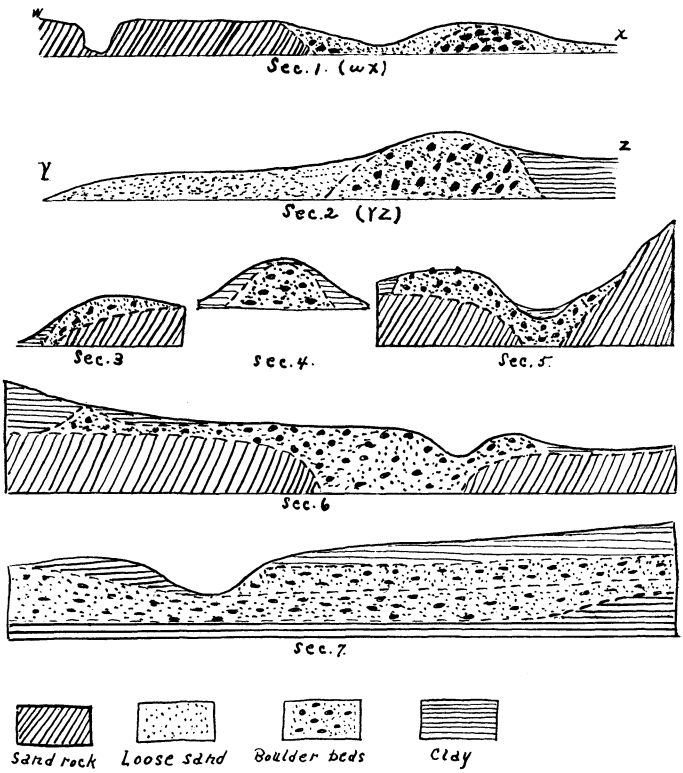

FIG. 2.— Section near Trempealeau, Wis. Scale about 240ft to an inch, except in Sec. 7, which is about 65ft to an inch. Datum, river level, except in Sec. 7.

confinement of the hills on the west side, at the same time changing from a nearly westerly to a southerly direction. Along this west side a large ridge of heavy bowlders is superimposed on a sandstone table. As the sandstone table falls away toward

the river the ridge also descends until it becomes merged with a bowlder bed which spreads out laterally to a moderate extent. Along the river front, this is cut into by the railroad excavation. The deposits are characterized throughout by the large average size of the material (equaling in this respect the ridge *a*, sec. 1) and by the abundance of limestone which forms masses at least as large as any. A smaller bowlder ridge can be seen on the east side after it leaves the hills.

Section 5 is made where the valley is still confined by the hill on the east.

Another valley, about the size and character of the last, descends from the eastern side of the same bluff and debouches into the center of Trempealeau village. In this case, also, a ridge extends across a sandstone table on one side, from the point where the valley leaves the hills. On the other side the valley skirts the foot of one of the main bluffs where the slope is gentle and the sides thickly covered with loess. A deep excavation has been made into this hillside for street construction. It shows the bowlder bed extending under the loess for a short distance, then suddenly rising into a ridge and as suddenly falling off. There appears to be a transverse ridge about where the line of section (sec. 6) runs, but it is not well defined. It is a difficult section to show.

In this valley the torrent course, after cutting through from forty to fifty feet of loess, has cut in places fifteen or twenty feet into the bowlder beds, thus giving opportunity for the study of the internal structure not elsewhere obtained. As, however, the section is not fresh it is only by much labor that it can be made available. It shows the bowlder beds alternating with beds of clay similar in appearance to the loess. Near the lower end of the ravine two bowlder beds occur above the bottom of the ravine and a hole seven feet deep in the bottom of the ravine struck the top of a third.

The thickness of a single bed ranges from about six to ten feet, varying considerably at different points. Roughly speaking the clay partings have about the same thickness as the bowl-

der beds. The general slope of the beds is only about one-third that of the ravine, so that they soon disappear from view, but further up the ravine and about thirty feet above the calculated horizon of the highest of the lower beds another one occurs about four feet thick, the parting being all clay. There appears to be another bed still further up.

In all the sections examined the extreme abruptness of the transition is noteworthy, the clay up to the very line of junction being absolutely free from stones.

Owing to the great labor of obtaining sections, and their small extent when obtained, it is impossible to answer many important questions regarding the form, extent, and relations of the beds.

Section 7 is fairly representative of the aspect of the beds in sections parallel to the valley. The relations shown at *p* were worked out carefully, and are of considerable interest. The upper bed, which terminates rather abruptly at that point, has a matrix composed mainly of sand, while in the lower bed the matrix is a compact clay. The transition from one to the other is quite abrupt.

Causes.—Although I should not like to express a final opinion as yet, I will, nevertheless, say that so far as the facts are known they seem to very strongly indicate one agent, while equally excluding others.

The agents capable of transporting material of the weight above described are few. Some of these may be dismissed with few words. Simple gravity, such as forms the talus of the hills, is excluded, since all the typical examples lie far outside its range of action. Wave action is also excluded. Neither can shore-ice offer any adequate explanation, although it can scarcely be doubted that it existed, and certain widely scattered bowlders, as well as certain sharply defined small pockets of local pebbles occasionally found embedded in the loess, may, with great probability, be assigned to this agent. Practically there are but two agents which need be considered. The one is torrential, the other, glacial action, in either case

operating during a period of subsidence, more or less interrupted by periods of partial reëlevation.

Torrential action.—Considered in the light of inherent probability, as well as in certain general aspects, this agent is doubtless the one we should select. The formations are strictly valley deposits. Torrents necessarily existed and must have produced characteristic deposits, and some of the beds at least might have been so formed. When, however, we take account of specific characteristics we find very grave difficulties, such as the transverse ridges. To account for these at all by torrential action it is necessary to regard them as ridges of erosion, the remains of a formation once occupying the entire upper part of the valley. The sequence of events which would thus be indicated is something as follows: (1) Subsidence, unstratified deposits; (2) Elevation, erosion; (3) Subsidence, stratified beds and loess, but no unstratified beds; (4) Reëlevation, erosion.

A study of local conditions furnishes several reasons why such a sequence of events must be regarded as violent and improbable. I will mention but one which alone seems to me to be fatal to it. As already stated, in the west valley above the ridge:

a. The loess covers everything high and low, even to the bottom of recent gullies, within a couple of rods of the upper end of the gorge, and a foot or two higher than its rock floor. Unless, therefore, we suppose that the gorge has received no appreciable deepening since the last elevation we must suppose that the early erosion extended deeper above the gorge than in the gorge itself. (How much deeper the loess extends, I do not know.)

b. The lateral ridges.—Not to occupy too much space I will refer to but one, the ridge marked *a* on the map. Assuming the two valleys to have been filled to the height of the ridge we should have to account for the removal of a very large amount of material, exceeding in the west valley the amount removed from its own gorge, yet its drainage area as compared with that

of the gorge is only as about 1 to 100. It would, morever, be necessary to account for the removal of material to a point considerably below present river level, which could only have been possible during a period of greater elevation, of which the gorge gives no indication.

c. There is excellent reason for believing that no torrents could have existed in these valleys capable of transporting the heavy bowlders found in the deposits. Of course I do not deny that torrents of sufficient power exist. I simply assert that in this as in all cases the question must be decided on the basis of local conditions. During the years that I have been familiar with the locality there have occurred several very heavy rains, and one of terrible severity, but never have I seen material transported reaching even the hundredth part of the weight of masses occurring in the deposits in question.

Moreover, a degree of subsidence sufficient to have allowed these deposits by such agency would have brought the valleys into the condition of broad flats with gentle slopes in which powerful torrential action would have been out of the question. We have also in the stratified beds, deposits formed under the conditions assumed, and having the characteristics we should expect.

Local glaciers.—That these, if we can suppose them to have existed, could have produced the specific effects above described, will not, I think, be questioned. I will, therefore, confine further remarks to facts having a negative bearing. Some of these have been anticipated in speaking of those favoring torrential agency. A further fact is that no undoubted case of glacial polishing or striation has yet been found, either on transported material or on the valley walls. The force of the objection is, however, practically destroyed by the fact that so far I have found only three exposures of rock so situated as to have fallen within the range of glacier action, while the transported material in sight, has been carried but a short distance and the greater share of that over beds of earlier deposit.

A more serious objection might be based on the general

insufficiency of the conditions for the production of glaciers. The present maximum height of Trempealeau bluff is but 548 feet above the river. It was, of course, less at that time in proportion to the amount of submergence.

But even were the elevation sufficient to allow of the formations of snow fields on the hilltops, and not elsewhere, still as most of the hills are little more than sharp ridges it would be quite impossible that the snow fields should have possessed volume sufficient to originate glaciers.

My own opinion is that under the influence of the wind the valleys themselves received a much larger annual accumulation of snow than would fall on the level, which, should it exceed in amount that which could be melted during the summer, would in time fill the valleys.

This suggests the further question whether were the valleys so filled there would be sufficient weight in the mass to give rise to glacial motion. A partial answer seems to be found in the small glaciers separated by Mt. Muir from the Sierra Nevada near the Yosemite Valley, which "have the structure and motion of true glaciers, but the largest is not more than a mile in length, and they vary in width from half a mile to a few feet." Some of those are therefore certainly smaller than the smallest indicated in this vicinity. Further information along this line would, however, be very desirable.

G. H. Squier.